Using air-quality feedback to encourage disadvantaged parents to create a smoke-free home

Citation for published version:
Semple, S, Turner, S, O'Donnell, R, Adams, L, Henderson, T, Mitchell, S, Lyttle, S & Amos, A 2018, 'Using air-quality feedback to encourage disadvantaged parents to create a smoke-free home: Results from a randomised controlled trial', *Environment International*, vol. 120, pp. 104-110. https://doi.org/10.1016/j.envint.2018.07.039

Digital Object Identifier (DOI):
10.1016/j.envint.2018.07.039

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Environment International

Environment International 120 (2018) 104–110

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Using air-quality feedback to encourage disadvantaged parents to create a smoke-free home: Results from a randomised controlled trial

Sean Semple[a,*], Stephen Turner[b], Rachel O'Donnell[c], Lynn Adams[d], Tracy Henderson[d], Shirley Mitchell[d], Susan Lyttle[d], Amanda Amos[e]

[a] Institute for Social Marketing, Faculty of Health Sciences and Sport, University of Stirling, Stirling, Scotland, United Kingdom
[b] Respiratory Group, Institute of Applied Health Sciences, University of Aberdeen, Aberdeen, Scotland, United Kingdom
[c] RCO Consulting, 1 Thorters Place, Edinburgh, Scotland, United Kingdom
[d] Tobacco Control, NHS Lanarkshire, Hamilton, Scotland, United Kingdom
[e] Usher Institute of Population Health Sciences and Informatics, University of Edinburgh, Edinburgh, Scotland, United Kingdom

ARTICLE INFO

Handling editor: Xavier Querol

Keywords:
Environmental Tobacco Smoke
Second-hand Smoke
Children
$PM_{2.5}$
Education
Intervention

ABSTRACT

Objective: To determine if low-cost air-quality monitors providing personalised feedback of household second-hand smoke (SHS) concentrations plus standard health service advice on SHS were more effective than standard advice in helping parents protect their child from SHS.

Design: A randomised controlled trial of a personalised intervention delivered to disadvantaged mothers who were exposed to SHS at home. Changes in household concentrations of fine Particulate Matter ($PM_{2.5}$) were the primary outcome.

Methods: Air-quality monitors measured household $PM_{2.5}$ concentrations over approximately 6 days at baseline and at one-month and six-months post-intervention. Data on smoking and smoking-rules were gathered. Participants were randomised to either Group A (standard health service advice on SHS) or Group B (standard advice plus personalised air-quality feedback). Group B participants received personalised air-quality feedback after the baseline measurement and at 1-month. Both groups received air-quality feedback at 6-months.

Results: 120 mothers were recruited of whom 117 were randomised. Follow up was completed after 1-month in 102 and at 6-months in 78 participants. There was no statistically significant reduction in $PM_{2.5}$ concentrations by either intervention type at 1-month or 6-months, nor significant differences between the two groups at 1-month ($p = 0.76$) and 6-month follow-up ($p = 0.16$).

Conclusions: Neither standard advice nor standard advice plus personalised air-quality feedback were effective in reducing $PM_{2.5}$ concentrations in deprived households where smoking occurred. Finding ways of identifying homes where air-quality feedback can be a useful tool to change household smoking behaviour is important to ensure resources are targeted successfully.

1. Introduction

Second-hand tobacco smoke (SHS) is a common indoor air pollutant linked to a wide range of respiratory (Snodgrass et al., 2016; Merianos et al., 2017), cardiovascular (Dunbar et al., 2013) and early life ill-health effects (Dai et al., 2017), with exposure more common in disadvantaged households (Hajizadeh & Nandi, 2016). Non-smokers who live with smokers can have high SHS exposures, particularly young children who spend much of their day at home with a smoker (Mills et al., 2012; Semple et al., 2015a). Globally it is estimated that 40% of children experience regular exposure to SHS with much of this exposure occurring in their own home (Mbulo et al., 2016). The global burden of this exposure is estimated to be over 600,000 deaths and almost 11 million disability-adjusted life-years per year. Children are particularly vulnerable to the effects of SHS exposure and suffer 28% of these deaths and 61% of this morbidity (Oberg et al., 2011).

Enabling parents to create a smoke-free home is challenging but it is one of the key ways that children's exposure to SHS can be reduced globally. Scotland is at the forefront of protecting children from exposure to SHS with the Scottish Government's 'Take it Right Outside' campaign including a world first: a governmental target to reduce the proportion of children exposed to SHS at home by 50% (from 12% to 6%) by 2020 (Scottish Government, 2014). Increased adoption of smoke-free homes in low income populations has also been shown to

* Corresponding author at: Institute for Social Marketing, Faculty of Health Sciences and Sport, University of Stirling, Stirling FK9 4LA, Scotland, United Kingdom.
E-mail address: sean.semple@stir.ac.uk (S. Semple).

https://doi.org/10.1016/j.envint.2018.07.039
Received 20 June 2018; Received in revised form 25 July 2018; Accepted 26 July 2018
Available online 01 August 2018
0160-4120/

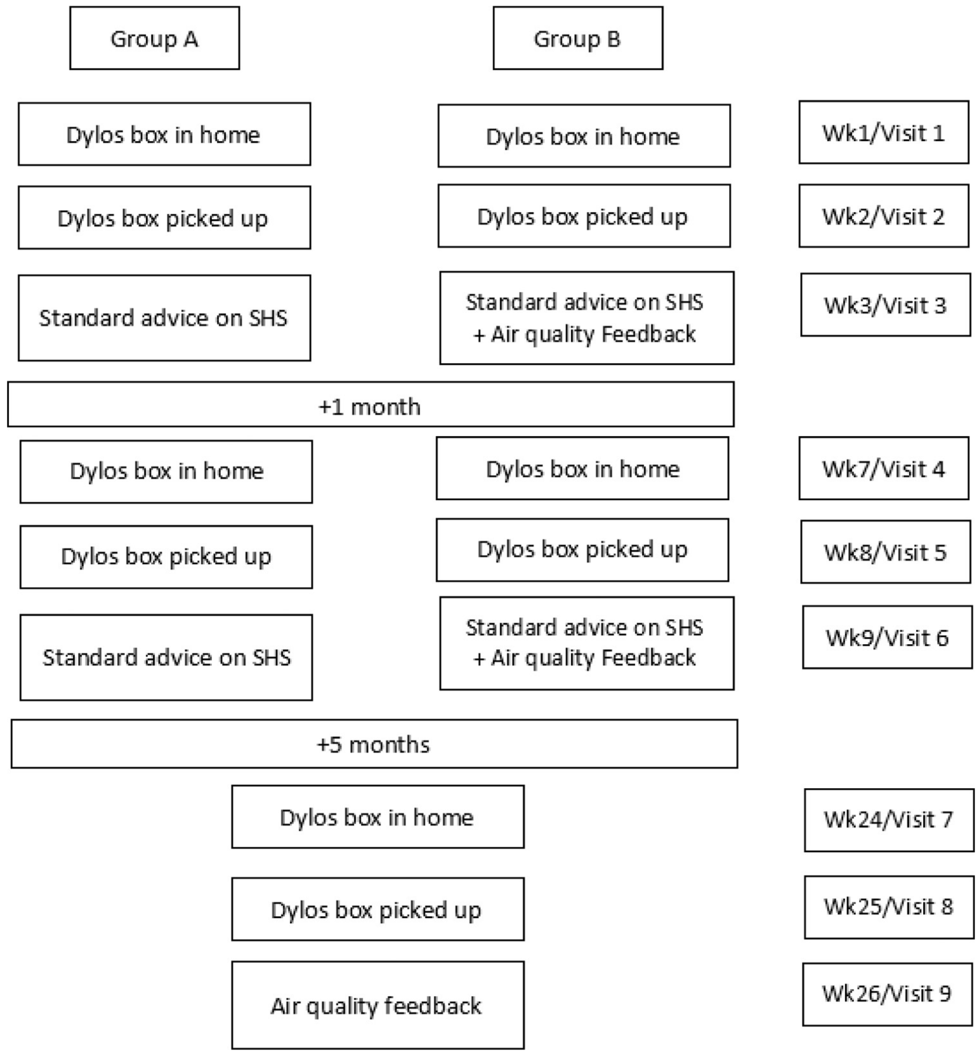

Fig. 1. Overall research design. Each participant received nine visits over a 26-week period. [Group A = standard care; Group B = standard care plus air quality feedback].

increase cessation rates and prevent relapse (Vijayaraghavan et al., 2013). There is a need for good quality evidence on ways to increase the proportion of smoke-free homes in different settings. The most recent Cochrane review (Baxi et al., 2014) of programmes to reduce children's exposure to SHS screened 57 relevant studies but identified that only 6 used objective measures of children's SHS exposure to evaluate intervention effectiveness. None of the included studies used air-quality feedback. A recent systematic review and meta-analysis (Rosen et al., 2015) identified seven interventions designed to encourage smoke-free homes that had used objective measures of household air quality as an outcome measure. The meta-analysis indicated that these approaches generally had an impact on reducing air concentrations of fine particulate matter ($PM_{2.5}$) or nicotine within the household; though all studies reported evidence of continuing SHS ‘contamination’ post-intervention.

Methods to measure SHS in indoor settings using airborne $PM_{2.5}$ as a marker of SHS concentrations have been used in tobacco control science over the past decade (Repace et al., 2006; Van Deusen et al., 2009; Sureda et al., 2012). Several studies have explored the concept of air-quality feedback to modify smoking behaviour in the home (Wilson et al., 2013a; Ratschen et al., 2018; Hughes et al., 2018).

There are considerable challenges in rolling out this type air-quality feedback intervention at scale. The REFRESH study identified low recruitment rates (when potential participants were approached via GP letter); the high cost of available instruments and technical complexity; and the labour costs of delivering, setting up and collecting instruments from participants' homes (Shaw et al., 2013). Recent work has identified low-cost air-quality monitoring devices that have the potential to address the practical problems of noise, cost and complexity of operation identified in previous studies (Semple et al., 2013).

The aim of the study was to determine if delivery of personalised air-quality feedback plus standard advice on the health effects of SHS was more effective than standard advice on its own in encouraging changes to household smoking as measured by objective assessment of $PM_{2.5}$ concentrations one-month later. The study was nested within the First Steps Programme (FSP) in Lanarkshire in Scotland (NHS Health Scotland, 2014), providing an opportunity to overcome many of the barriers identified in the REFRESH study (Wilson et al., 2013b) in terms of recruiting disadvantaged parents, embedding the intervention within an existing service and use of a simpler, low-cost device to deliver air quality feedback.

2. Methods

2.1. Study design

This was a randomised controlled trial which compared standard advice to achieve a smoke-free home against standard advice plus personalised air-quality feedback. Vulnerable mothers who smoked or lived with smokers and were engaged with the Lanarkshire FSP were eligible. FSP is an early intervention programme provided by the National Health Service in Lanarkshire, Scotland, providing vulnerable first-time mums with intensive, free, one-to-one support during and after pregnancy to give their babies the best possible start in life. Support includes considering the child's exposure to SHS and where appropriate exploring options to reduce this. Over 30% of mothers involved in the programme are smokers with 48% of homes having one or more smoking adult resident.

First Steps (FS) workers identified clients who were thought likely to have SHS exposure in the home either from self-report of household smoking or observations of the presence of SHS within the home. Participants were excluded from the study if they were: under 16; they were unable to give informed consent due to physical or mental incapacity; or there was no smoker resident within the household. Information sheets were provided and written informed consent gained. Participants were randomised to group A or B by a member of the research team blind to the participants' details, using the ID number and randomisation function in Microsoft Excel. A short baseline questionnaire was completed to determine self-reported current smoking, household smoking rules and attitudes towards smoking.

Questionnaires assessed changes in smoking, household rules and quit attempts at the 1- and 6-month follow-ups. All study participants received a £10 shopping voucher on completing the baseline and a further £20 on completion of the 6-month follow-up visit. The primary outcome was change in the household $PM_{2.5}$ concentration after one month. Ethical approval for the study was obtained from the NHS North of Scotland Research Ethics Committee (REC reference: 14/NS/0030; Protocol number: 2/012/14; IRAS project ID: 150095).

2.2. Intervention

Project home visits were built into the existing FS programme of weekly contacts with clients. Full engagement over the 6-month period involved nine visits where study materials were used. Fig. 1 shows the overall research design. In summary, both groups had $PM_{2.5}$ measurements made in their homes at three time points: baseline, one-month after they received the intervention and then at approximately six months post intervention. Group A participants received standard UK National Health Service (NHS) advice on the harmful effects of SHS delivered as 'very brief advice' similar to that recommended by the UK National Centre for Smoking Cessation and Training, after the baseline measurement (visit 3 – week 3) and again at follow-up (visit 6 – approximately week 9). Group B participants received this same standard NHS SHS advice but additionally received personalised air-quality feedback at the baseline measurement and follow-up visits.

Feedback of personalised air-quality measurements involved 1-to-1 discussion between the FSP worker and mother using a simple 4-page pamphlet which included: their air-quality feedback graph showing temporal changes in $PM_{2.5}$ concentrations over the measurement period; summary quantitative information on the air-quality measurements in their home; information on the effects of SHS; and practical advice on how to reduce SHS. The feedback included information on the proportion of time when household $PM_{2.5}$ concentrations exceeded the World Health Organisation (WHO) guidance value of 25 $\mu g/m^3$ as a health-based air quality benchmark (World Health Organisation, 2005). The air quality feedback pamphlet was produced by the FSP administrator and provided to the participant usually within one week of the measurements having taken place. Feedback was provided to Group B at visit 3 (week 3 after recruitment), again at visit 6 (approximately week 9), and finally at visit 9 (approximately week 26). Group A received all their air quality feedback only on conclusion of their involvement, at visit 9 (week 26).

2.3. Training

Seventeen FSP workers who delivered the intervention received a half-day training course which included: Good Clinical Practice; the health effects of SHS; the recruitment process; using the Air Quality Monitor; and how to discuss the measurements with mothers to encourage them to make their homes smoke-free. The FSP administrator (TH) was trained in downloading data from air-quality instruments and preparing personalised feedback graphs using Microsoft Excel.

2.4. $PM_{2.5}$ measurements

A Dylos DC1700 Air Quality Monitor (Dylos Inc., CA, USA) was installed in the main living-room of participants' homes to measure $PM_{2.5}$ in the home for 3–7 days on three occasions (baseline, +1 month post-intervention, +6 months post-intervention). The living-room was selected as the area of the home where the family will spend most of their waking hours within the home setting. There is also recent evidence that living-room and child's bedroom concentrations of air nicotine are well correlated (Arechavala et al., 2018). The Dylos is a low-cost instrument that has been utilised by several research groups to provide real-time data on $PM_{2.5}$ as a proxy for SHS concentrations (Hughes et al., 2018; Klepeis et al., 2013). It is a simple laser-based particle counter that has been shown to provide data on SHS aerosol that is broadly comparable with data provided by 'gold-standard' optical particle counting instruments (Semple et al., 2015b). It costs approximately £300 (US $400); has near-silent operation and is simple to install and activate to logging mode with a single press of one button.

2.5. Power calculation and sample size

Using air-quality at 1-month as our primary outcome measure the study was powered (> 80% power with alpha level of 0.05) to detect a difference of at least 30% between groups. To achieve this power we sought to recruit 120 participants to have approximately 50 participants in each arm at the 1-month follow-up stage.

2.6. Analysis

The data from each instrument was downloaded using proprietary software (Dylos Logger (v1.6)) and exported to Microsoft Excel to allow temporal analysis and production of graphical feedback. Particle number concentrations were converted to mass concentrations using a previously validated method (Semple et al., 2015b). For each sampling period in each household a customized Excel spreadsheet was used to produce summary statistics of $PM_{2.5}$ concentrations including the mean, the peak value, and the percentage of measurement time the instrument recorded values above thresholds. Differences in characteristics between groups and between baseline and follow-up $PM_{2.5}$ mean concentrations were analysed using IBM SPSS (v23) using Student's *t*-tests for continuous variables and Pearson's Chi Square for categorial variables. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Recruitment

Recruitment took place between June 2014 and February 2016. 171 mothers enrolled in the FSP were invited to take part, of which 120 agreed (response rate 70.2%). Of these, 117 completed baseline measurements, 59 in Group A and 58 in Group B. 102 completed the 1-month follow-up with 78 completing the 6-month stage. Characteristics of the participants are provided in Table 1. Reflecting the population of young, vulnerable mothers that this cohort was drawn from, participants' median and Inter-Quartile Range (IQR) age was 21 (19–23) with 54% of participants living in areas in the bottom 20% in the Scottish

Table 1
Characteristics of study participants [Group A = standard care; Group B = standard care plus air quality feedback].

	Overall	Group A	Group B	p value
Number of participants	117	59	58	
Age: mean (range) in years	21.6 (17–43)	21.4 (17–38)	21.7 (17–43)	0.666
SIMD[a]: mean (range)	2.8 (1–10)	2.7 (1–7)	3.0 (1–10)	0.449
Smokers	81 (69%)	36 (61%)	45 (76%)	0.071
Pregnant	29%	37%	21%	0.048
Garden space available	67%	75%	64%	0.106
Self-report smoke-free home at baseline	27%	23%	32%	0.270
Baseline measurement duration: mean (range) in minutes	7890 (2213–9056)	7956 (2213–9056)	7824 (2237–9056)	0.709
Baseline $PM_{2.5}$ average: mean (range) in μg/m^3	67.5 (4.5–424)	73.4 (4.5–424)	61.4 (5.1–295)	0.418
Baseline $PM_{2.5}$ peak[b]: mean (range) in μg/m^3	547 (48.3–1126)	558 (48.3–1105)	537 (63–1126)	0.678
Baseline $PM_{2.5}$% time > 25 μg/m^3: mean (range)[c]	40.0 (1–100)	39.0 (1–100)	38.9 (1–100)	0.984

[a] The Scottish Index for Multiple Deprivation decile (A score of 1 is the 10% most deprived; 10 is the 10% most affluent).
[b] The peak exposure refers to the highest 1-minute concentration recorded in the home.
[c] The 25 μg/m^3 threshold is used as a marker of the proportion of time where the household $PM_{2.5}$ concentration exceeded the World Health Organisation 24 h guidance value (World Health Organisation, 2005) for fine particulate pollution.

Index of Multiple Deprivation (SIMD). Approximately two-thirds (69%) were smokers and three-quarters lived in a flat or tenement (72%), with 1 in 3 reporting no access to private or shared garden space (33%). The only statistical difference between the two groups was that participants in the standard care group (A) were more likely to be pregnant at the time of recruitment.

3.2. Air quality results

A total of 2,278,614 min of valid air-quality data was obtained from 297 visits to participants' homes. Table 1 provides a breakdown of household $PM_{2.5}$ measurements made at baseline including the household average, peak and percentage of time measurements were above the WHO 24-hour guidance value (25 μg/m^3) (World Health Organisation, 2005).

After excluding participants who did not complete the 1-month follow up or for whom the measurement duration at the follow-up visit was < 24 h (n = 2 at 1-month; n = 1 at 6-months) the median (95% Confidence Interval) difference between 1-month and baseline $PM_{2.5}$ measurements for Group A (n = 50) was +3.8 (−16.4 to 28.8); Group B (n = 50) was 1.1 (−22.3 to 24.5) μg/m^3 (p = 0.76 for comparison). Similar results were found for comparison between the 6-month and baseline $PM_{2.5}$ measurements, with Group A (n = 40) −1.7 (−18.3 to 4.5); Group B (n = 37) −1.0 (−8.1 to11.4) μg/m^3 (p = 0.16). A similar pattern was found when the change was expressed as a percentage change relative to the baseline measurement to account for the variation in measured concentrations at baseline. Table 2 provides these data in summary form. Fig. 2 illustrates this change by paired measurements for each home with each data point providing the baseline and 1-month follow-up average $PM_{2.5}$ concentrations measured.

The baseline $PM_{2.5}$ concentrations from homes where the participants self-reported having a smoke-free home at baseline (i.e.

Table 2
Change in $PM_{2.5}$ between baseline and +1 and +6 month follow-up. Expressed as an absolute change and as a percentage of the baseline measurement. [Group A = standard care; Group B = standard care plus air quality feedback].

	Baseline to +1 month change		Baseline to +6 months change	
Allocation group	A	B	A	B
Number of participants	50	50	40	37
Change in average $PM_{2.5}$ μg/m^3: median and 95% Confidence Interval	+3.8 (−16.4 to 28.8)	+1.1 (−22.3 to 24.5)	−1.7 (−18.3 to 4.5)	-1.0 (−8.1 to 11.4)
Change in average $PM_{2.5}$ as a percentage of baseline measurement: median and 95% Confidence Interval	+20% (−6 to 43)	+3% (−24 to 36)	−8% (−34 to 13)	−6% (−27 to 40)

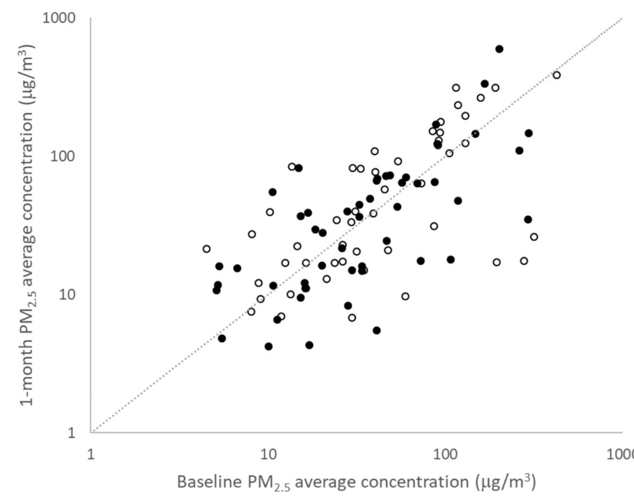

Fig. 2. Scatterplot illustrating the paired $PM_{2.5}$ average values from each home measured at baseline and then again at +1 month, divided by allocation group (A group = clear circles; B group = black circles). The black 1:1 line represents zero change; points to the left of the line indicate an increase in SHS levels after 1 month and points to the right of the line indicate homes that had reduced SHS levels after 1 month.

responded positively to the statement that ‘Smoking is not allowed inside your home’) (n = 31) was found to be significantly lower than those who confirmed smoking (n = 82) was allowed in the home. The median and (95% CI) value was 14.9 (10.7–20.8) compared to 48.2 (39.3–75.3) μg/m^3. Analysis was also carried out after excluding these 31 self-reported smoke-free homes (at baseline) but the lack of significant change and similarity in response between the intervention groups was maintained.

3.3. Self-reported changes in household smoking

Questionnaires were completed by 114 participants at baseline; 95 at 1-month and 72 at 6-month stages. Not all participants provided a response to all questions. At 1-month 10/47 Group A participants reported becoming a ‘smoke-free’ home compared to 12/45 in Group B (Pearson's Chi-square = 0.205). Similar changes were noted at 1-month in self-reported quitting (4 from Group A and 2 from Group B) or self-reported reduction in smoking (6 from Group A and 10 from Group B). At 1-month, reported smoking by the participant ‘in the presence of children inside the home’ was reduced for 5/46 participants in Group A and 5/47 in Group B (none reported smoking ‘more than before’) (p = 0.284). Similarly, 8/44 (Group A) and 7/48 (Group B) participants reported other smoking adults in the home ‘smoking less than before’ in the presence of children at 1-month follow-up (p = 0.307).

4. Discussion

This study is the first to trial the use of air-quality feedback as an intervention to encourage smoke-free homes delivered in a real-world setting as part of health professionals' routine work with smoking clients. The study demonstrated that measurement of household air quality and personalised feedback of results to a group of disadvantaged mothers of young children was achievable at scale and could be incorporated by health professionals within existing health care services provided to parents. Recruitment was high with over 70% of eligible mothers agreeing to participate in the study, indicating a high level of interest in receiving this type of individual data about SHS concentrations in the home. Follow-up participation was also good with over 87% of those who completed the baseline measurements taking part at 1-month, and 67% at 6-month follow-up. However, this adequately powered RCT using an objective measurement of smoke-free status ($PM_{2.5}$) found that home SHS levels did not change in either arm of the trial. While $PM_{2.5}$ feedback has proven effective in reducing household SHS concentrations after selection from the general population, this study indicates that different strategies may be required for vulnerable families such as those included in this trial.

The practicalities of delivering the intervention generally worked well despite the complexities of: installing the device three times per household; collecting one-week later; having the data downloaded and the feedback pamphlet generated centrally by one FSP administrator; and meeting with the participant as soon as possible thereafter. Logistical difficulties highlighted by the FSP workers and administrator included: the length of time it took to download the data; the need to prepare hard-copies of feedback reports in colour (FSP workers did not have local printing facilities); liaison with FSP workers who had substantial caseloads and covered large geographical areas.

The pre-intervention baseline household $PM_{2.5}$ concentrations showed broadly similar median (34 µg/m^3) and IQR (16–88 µg/m^3) values to those previously reported in other Scottish homes where smoking is permitted (median 31 µg/m^3; IQR (10–111 µg/m^3)) (Semple et al., 2015a). At baseline nearly two-thirds of homes (64.1%) had average $PM_{2.5}$ concentrations greater than the WHO guidance value for 24-hour average exposure (25 µg/m^3) with 1 in 5 (20.5%) showing average values > 100 µg/m^3. It is worth considering that these 24-hour $PM_{2.5}$ levels would generate considerable media attention if they were present in outdoor air in urban environments. Indeed, these data suggest that fine particulate air pollution is greater than the annual average $PM_{2.5}$ concentration in Beijing (51 µg/m^3) (Xie et al., 2015) one of the most polluted cities in the world, in about one-third of the homes that took part in this study.

These results can be compared to other studies that have used personalised air quality feedback, albeit from different populations. The REFRESH study recruited 59 smoking mothers in Scotland and provided $PM_{2.5}$ measurement data over a 24-hour period as the primary tool in a motivational interview aimed at empowering parents to make their home smoke-free (Wilson et al., 2013a). That study found that mothers who received air-quality feedback reduced $PM_{2.5}$ concentrations by approximately one-third although the study was too small to detect a difference with the control group. More recent work by Ratschen et al. (2018) studied a similar approach with disadvantaged smoking parents in Nottingham. That study compared a complex intervention combining personalised air quality feedback, behavioural support and nicotine replacement therapy for temporary abstinence with usual care involving standard advice. The 24 h $PM_{2.5}$ concentration in intervention homes reduced by about one-third at the 12-week follow-up. Hughes et al. (2018) have reported an intervention involving an air-quality instrument with warning lights and alarms to provide real-time feedback on particle concentrations in smokers' home. Their work showed an average reduction of approximately 19% in households receiving this feedback compared to just 6.5% reduction in control homes.

The reasons for the lack of change in $PM_{2.5}$ concentrations in the current study are unclear but may involve the disadvantages experienced by this group and include the dual barriers of a lack of opportunity to make changes and lack of support from other smoking adults. Qualitative interviews carried out with a selection of study participants (O'Donnell et al., 2018) demonstrated that the intervention increased mothers' capability to change smoking behaviour in the home, through better awareness of the risks to their children from SHS exposure. However, taking significant action was often constrained by their limited, and often changing, social and environmental opportunities, including smoking of other adults in the home setting. Recent work on the barriers, motivators and enablers to creating a smoke-free home have shown the complex interplay that exists in many homes can make the process difficult (Rowa-Dewar et al., 2015; Passey et al., 2016).

The intervention was based on review of behavioural interventions to reduce indoor smoking by parents which led to the development of the AFRESH behaviour theory programme described in detail elsewhere (Dobson et al., 2017). Review of the literature indicated that incorporating objectively assessed feedback data and motivational interviewing appear to be the most popular adopted intervention methods and the most effective for SHS reduction with parents and caregivers of young children. Simply providing written information about the risks of SHS is not an effective strategy for this specific behaviour change type and instead ongoing support and interaction may play a vital role in the success of such SHS reduction interventions. The review also identified that it is necessary to strike a balance between making the intervention intensive enough to be effective but also ensuring too many sessions are not required, as the target population (often socioeconomically disadvantaged people) may find multiple session attendance problematic.

4.1. Strengths and limitations

In addition to the objective assessment of air-quality in each home, a particular strength of the study over other previous work was the duration of measurements. Air-quality data were collected for an average of 127 h (5.3 days) during each stage in each home. In addition to the potential bias from the Hawthorne effect during short measurement periods (McCambridge et al., 2014), FSP workers reported that household activity (number of adults, number of cigarettes smoked, hours spent indoors etc.) was often highly variable due to complex issues around substance misuse, unemployment and changing relationships. There is significant potential to misclassify household concentrations of SHS through the use of snapshot or even 24 h measurement of $PM_{2.5}$ and longer duration measurement reduces the chance of people changing their behaviour while measurements are being made. Gathering data over 3–7 days is likely to have reduced these potential biases and provided a more accurate picture of SHS concentrations within each home at baseline and follow-up.

There were several limitations mostly due to the delivery challenges of real-world settings, structures and events. For example, a small number of participants moved home during the 6-months and so measurements were not always taken in the same setting. Similarly, partners or other adults living in the home sometimes changed between baseline and follow-up and so conditions were not always directly comparable. The intervention was delivered by 17 FSP workers and while all received identical training, the type of feedback and advice received by participants may have differed. The intervention was intentionally delivered as part of an existing relationship between the participant and their FSP worker, and possibly pre-existing differences in those relationships may have influenced the way the information was received and acted on.

In a few cases devices were switched off for periods of time during measurements. This was sometimes due to interruptions in electricity supply or may have been due to participants/others in the home deciding to switch the device off because of the desire to prevent the device measuring high levels of SHS during smoking. However, compliance was high with the number and duration of periods of lost data small in comparison to the time instruments were in homes. There was no evidence that data loss was more frequent at follow-up than baseline and so we do not think this had a significant impact on our results.

A further limitation of the study is the use of $PM_{2.5}$ as a marker for SHS. While this method has been used extensively in tobacco control research as a means of quantifying SHS concentrations (Repace et al., 2006; Van Deusen et al., 2009; Sureda et al., 2012), $PM_{2.5}$ is not specific to tobacco smoke and can arise from non-smoking sources such as ambient air pollution, cooking and use of solid fuels. While it is possible that some increases of $PM_{2.5}$ may have been due to non-smoking activity (particularly frying of food), it is also possible that smoking may have continued in these homes during periods when the participant was unaware of the behaviour of (other) smoking adults. We believe that our $PM_{2.5}$ measurements are likely to provide robust information on household SHS data and note data from the Scottish Government ambient air quality monitor located in Hamilton, the administrative centre of the Lanarkshire area, that shows low PM concentrations and no discernible seasonal variation with monthly average PM_{10} concentrations across 2015 ranging from 14 to 21 $\mu g/m^3$ ($PM_{2.5}$ is typically about 60% the value of PM_{10}) (Air Quality in Scotland; Ricardo Energy & Environment, 2016) and draw on $PM_{2.5}$ concentration data gathered from previous studies in Scotland that showed average concentrations in typical smoke-free homes were 3 $\mu g/m^3$ (Semple et al., 2015a) and 8–16 $\mu g/m^3$ even when combustion sources such as coal, wood and gas were used for heating or cooking purposes (Semple et al., 2012). While measurement of air nicotine would provide a tobacco-specific method of quantifying SHS concentrations, this approach would currently not provide time-resolved information and would require expensive (and slow) chemical laboratory analysis: something that is likely to be a barrier to any future use of this intervention approach. New technologies under development may provide real-time nicotine concentrations using low-cost methods (Liu et al., 2013) or utilise data on particle size distributions from different emission sources to differentiate SHS from other household aerosols (Dacunto et al., 2015). Work on using the differential response of the Dylos to fine and coarse PM to identify SHS from other aerosols may also provide a way forward in quantifying the contribution of smoking to indoor air pollution (Dobson & Semple, 2018).

The intervention method used delayed feedback of air quality data and provided this feedback only once at baseline and again at the one-month follow-up. It was necessary to take the device back to the office to perform the download and generation of the graphical and numerical feedback. This meant that feedback was typically provided one week after completion of the measurement period. There is evidence that rapid feedback is more effective in eliciting change in health and safety behaviours (Marciano et al., 2015) and future work should examine methods to provide more immediate feedback to those engaging in smoke-free home interventions. Providing air quality feedback on just a single occasion (prior to the follow-up assessment) may be another reason that the study showed no effect on those receiving the intervention. Work by Klepeis and colleagues has begun to explore the use of warning lights and alarms on air quality monitors used to measure SHS (Klepeis et al., 2013). Our group has also recently initiated a study to examine SHS concentration feedback using a Dylos connected to the internet to upload data in real-time to then provide participants with mobile phone SMS, email and telephone feedback and guidance [ClinicalTrials.gov Identifier: NCT03151421].

It is also possible that the intervention was not sufficiently strong to change behaviour in a sustained manner. There is evidence from the literature on health warnings that 'shock' is often short-lived and does not produce long-term changes in smoking behaviour (Swayampakala et al., 2018). This may be particularly true if there are significant barriers to enacting change and the subject has limited capacity to change: the single parent caring for a young child in a high-rise flat has fewer options in terms of modifying their smoking behaviour compared to someone living with a partner in a ground floor home with access to garden space.

We also note that the current best practice of offering standard NHS advice on the health harms of SHS produced no reductions in $PM_{2.5}$ concentration in the control arm of the study. We are not aware of any studies that have evaluated the effectiveness of 'standard' or 'very brief advice' on SHS from Health Professionals to smoking parents and recommend that future work looks at how this can be improved and better targeted to help protect children from SHS at home.

The FSP provides support to young mothers and the intervention was therefore targeted at this group despite the fact that other adults (partners, parents, visitors) may be smokers in the home. While the intervention hoped to provide mothers with the motivation and tools to engage with other adult smokers this is very likely to be subject to differences in family dynamics and social circumstances. Future work should consider an 'all household' approach where the intervention is delivered to all those who smoke in the home and have an interest in the child's health (Semple et al., 2018).

4.2. Conclusions

Personalised feedback of air-quality information using low-cost devices can be successfully integrated into routine services provided by health care providers. The overall results show that, in this group of disadvantaged mothers, there was no change in household SHS concentrations after delivery of the intervention. On this basis it seems unlikely that personalised air-quality feedback is sufficient, in itself, to change smoking behaviour in disadvantaged households in Scotland and similar countries where there is already a high awareness of the risks of SHS. Providing personalised air-quality feedback may not be suitable for all groups of smoking parents and may instead need to be tailored to those at a more advanced stage of change in terms of household smoking rules and, importantly, with the physical and social opportunities to change. Further work is required to identify the types of smoking households where air-quality feedback can play a role in supporting parents to protect their children from SHS. More immediate feedback methods delivered to all adults in the home may be key to achieving sustained household behaviour change in relation to smoking.

Competing interests

None of the authors have any competing interests.

Acknowledgements

Ms. C Briffa-Watt, Ms. L Bruce, Ms. J Madden, All Lanarkshire First Steps Programme workers, and all the mothers who participated in the study.

Contribution statement

SS, ST, AA, SM, SL and ROD conceived, designed the study and obtained funding. TH, SM and LA managed the FSP workers and the collection of the data; TH carried out the production of the air-quality feedback for each participant. SS analysed the data, wrote the first draft of the manuscript and is the guarantor for this study. All authors made contributions to and approved the final manuscript.

Funding

This work was funded by the Scottish Government Chief Scientist Office (CZH_4_983).

References

Air Quality in Scotland South Lanarkshire, Hamilton. 2015 PM10 data extracted from.

http://www.scottishairquality.co.uk/latest/site-info?site_id=SL05&view=statistics, Accessed date: 19 July 2018.
Arechavala, T., Continente, X., Pérez-Ríos, M., et al., 2018. Second-hand smoke exposure in homes with children: assessment of airborne nicotine in the living room and children's bedroom. Tob. Control. 27, 399–406.
Baxi, R., Sharma, M., Roseby, R., et al., 2014. Family and carer smoking control programmes for reducing children's exposure to environmental tobacco smoke. Cochrane Database Syst. Rev. 3, CD001746 (Mar 1).
Dacunto, P.J., Klepeis, N.E., Cheng, K.C., et al., 2015. Determining PM2.5 calibration curves for a low-cost particle monitor: common indoor residential aerosols. Environ. Sci.: Processes Impacts 17, 1959–1966.
Dai, X., Dharmage, S.C., Lowe, A.J., et al., 2017. Early smoke exposure is associated with asthma and lung function deficits in adolescents. J. Asthma 54, 662–669.
Dobson, R., Semple, S., 2018. "How do you know those particles are from cigarettes?": An algorithm to help differentiate second-hand tobacco smoke from background sources of household fine particulate matter. Environ. Res. 166, 344–347.
Dobson, R., O'Donnell, R., De Bruin, M., Turner, S., Semple, S., 2017. Using air quality monitoring to reduce second-hand smoke exposure in homes: the AFRESH feasibility study. Tob. Prev. Cessation 3, 117.
Dunbar, A., Gotsis, W., Frishman, W., 2013. Second-hand tobacco smoke and cardiovascular disease risk: an epidemiological review. Cardiol. Rev. 21, 94–100.
Hajizadeh, M., Nandi, A., 2016. The socioeconomic gradient of secondhand smoke exposure in children: evidence from 26 low-income and middle-income countries. Tob. Control. 25 (e2), e146–e155.
Hughes, S.C., Bellettiere, J., Nguyen, B., et al., 2018. Randomized trial to reduce air particle levels in homes of smokers and children. Am. J. Prev. Med. 54, 359–367 (Jan 2. pii: S0749-3797(17)30640-2).
Klepeis, N.E., Hughes, S.C., Edwards, R.D., et al., 2013. Promoting smoke-free homes: a novel behavioral intervention using real-time audio-visual feedback on airborne particle levels. PLoS One 8, e73251.
Liu, Y., Antwi-Boampong, S., BelBruno, J.J., et al., 2013. Detection of secondhand cigarette smoke via nicotine using conductive polymer films. Nicotine Tob. Res. 15, 1511–1518.
Marciano, H., Setter, P., Norman, J., 2015. Overt vs. covert speed cameras in combination with delayed vs. immediate feedback to the offender. Accid. Anal. Prev. 79, 231–240.
Mbulo, L., Palipudi, K.M., Andes, L., et al., 2016. Secondhand smoke exposure at home among one billion children in 21 countries: findings from the Global Adult Tobacco Survey (GATS). Tob. Control. 25 (e2), e95–e100.
McCambridge, J., Witton, J., Elbournec, D.R., 2014. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. J. Clin. Epidemiol. 67, 267–277.
Merianos, A.L., Jandarov, R.A., Mahabee-Gittens, E.M., 2017. Secondhand smoke exposure and pediatric healthcare visits and hospitalizations. Am. J. Prev. Med. 53, 441–448.
Mills, L.M., Semple, S.E., Wilson, I.S., et al., 2012. Factors influencing exposure to secondhand smoke in preschool children living with smoking mothers. Nicotine Tob. Res. 14, 1435–1444.
NHS Health Scotland, 2014. The first steps programme. http://www.healthscotland.com/topics/resourcechp/evaluate/casestudies/Firststeps.aspx, Accessed date: 31 January 2018.
Oberg, M., Jaakkola, M.S., Woodward, A., et al., 2011. Worldwide burden of disease from exposure to second-hand smoke: a retrospective analysis of data from 192 countries. Lancet 8 (377), 139–146.
O'Donnell, R., Amos, A., Turner, S., Adams, L., Henderson, T., Lyttle, S., Mitchell, S., Semple, S., 2018. Understanding Mediators of Behaviour Change in a Smokefree Homes Intervention for Low Income Mothers: A Qualitative Analysis Informed by the COM-B Model. Submitted to Addiction. April. .
Passey, M.E., Longman, J.M., Robinson, J., et al., 2016. Smoke-free homes: what are the barriers, motivators and enablers? A qualitative systematic review and thematic synthesis. BMJ Open 6, e010260.
Ratschen, E., Thorley, R., Jones, L., et al., 2018. A randomised controlled trial of a complex intervention to reduce children's exposure to secondhand smoke in the home. Tob. Control. 27 (2), 155–162 (Apr 21. pii: tobaccocontrol-2016-053279).
Repace, J.L., Hyde, J.N., Brugge, D., 2006. Air pollution in Boston bars before and after a smoking ban. BMC Public Health 6, 266.
Ricardo Energy & Environment, 2016. PM2.5 and PM10 in Scotland Investigation of concentrations and ratios of PM2.5 and PM10 across Scotland to help inform potential changes to air quality strategy objectives and local air quality management. Report for the Scottish Government ED57729. http://www.scottishairquality.co.uk/assets/documents/technical%20reports/pm2.5-pm10ratio_29Mar2016-FINAL_Version_Approved.pdf, Accessed date: 19 July 2018.
Rosen, L.J., Myers, V., Winickoff, J.P., et al., 2015. Effectiveness of interventions to reduce tobacco smoke pollution in homes: a systematic review and meta-analysis. Int. J. Environ. Res. Public Health 12, 16043–16059.
Rowa-Dewar, N., Lumsdaine, C., Amos, A., 2015. Protecting children from smoke exposure in disadvantaged homes. Nicotine Tob. Res. 17, 496–501.
Scottish Government, 2014. Campaign urges smokers to 'take it right outside. https://news.gov.scot/news/campaign-urges-smokers-to-take-it-right-outside, Accessed date: 31 January 2018.
Semple, S., Garden, C., Coggins, M., et al., 2012. Contribution of solid fuel, gas combustion, or tobacco smoke to indoor air pollutant concentrations in Irish and Scottish homes. Indoor Air 22, 212–223.
Semple, S., Apsley, A., MacCalman, L., 2013. An inexpensive particle monitor for smoker behaviour modification in homes. Tob. Control. 22, 295–298.
Semple, S., Apsley, A., Azmina Ibrahim, T., et al., 2015a. Fine particulate matter concentrations in smoking households: just how much secondhand smoke do you breathe in if you live with a smoker who smokes indoors? Tob. Control. 24 (e3), e205–e211.
Semple, S., Ibrahim, A.E., Apsley, A., et al., 2015b. Using a new, low-cost air quality sensor to quantify second-hand smoke (SHS) levels in homes. Tob. Control. 24, 153–158.
Semple, S.Abidin, E.Amos, A.Hashim, Z.Siddiqi, K.Ismail, N. On behalf of the participants of the smoke-free homes workshop. Commentary: The Kuala Lumpur charter on smoke-free homes. BMJ tobacco control blog. https://blogs.bmj.com/tc/2018/06/25/the-kuala-lumpur-charter-on-smoke-free-homes/, Accessed date: 19 July 2018.
Shaw, A., Ritchie, D., O'Donnell, R., et al., 2013. Creating smoke-free homes for children. Nurs. Times 109, 28–30.
Snodgrass, A.M., Tan, P.T., Soh, S.E., et al., 2016. Tobacco smoke exposure and respiratory morbidity in young children. Tob. Control. 25 (e2), e75–e822.
Sureda, X., Martínez-Sánchez, J.M., López, M.J., et al., 2012. Secondhand smoke levels in public building main entrances: outdoor and indoor PM2.5 assessment. Tob. Control. 21, 543–548.
Swayampakala, K., Thrasher, J.F., Yong, H.H., Nagelhout, G.E., Li, L., Borland, R., Hammond, D., O'Connor, R.J., Hardin, J.W., 2018. Over-time impacts of pictorial health warning labels and their differences across smoker subgroups: results from adult smokers in Canada and Australia. Nicotine Tob. Res. 20, 888–896.
Van Deusen, A., Hyland, A., Travers, M.J., et al., 2009. Secondhand smoke and particulate matter exposure in the home. Nicotine Tob. Res. 11, 635–641.
Vijayaraghavan, M., Messer, K., White, M.M., Pierce, J.P., 2013. The effectiveness of cigarette price and smoke-free homes on low-income smokers in the United States. Am. J. Public Health 103, 2276–2283.
Wilson, I., Semple, S., Mills, L.M., et al., 2013a. REFRESH–reducing families' exposure to secondhand smoke in the home: a feasibility study. Tob. Control. 22, e8.
Wilson, I.S., Ritchie, D., Amos, A., et al., 2013b. 'I'm not doing this for me': mothers' accounts of creating smoke-free homes. Health Educ. Res. 28, 165–178.
World Health Organisation, 2005. WHO air quality guidelines. Global update. http://www.who.int/phe/health_topics/outdoorair_aqg/en/, Accessed date: 31 January 2018.
Xie, Y., Wang, Y., Zhang, K., et al., 2015. Daily Estimation of Ground-Level PM2.5 Concentrations over Beijing using 3 km Resolution MODIS AOD. Environ. Sci. Technol. 49, 12280–12288.